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Shipboard Antenna Concepts:

Structurally Independent 2- to 6-MHz Transmit Antenna Design

R. S. Abramo

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NAVAL OCEAN SYSTEMS CENTER
San Diego, California 92152-5000

J. D. FONTANA, CAPT, USN
Commander

R. T. SHEARER, Acting
Technical Director

ADMINISTRATIVE INFORMATION

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W. E. Kordela, Head
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R. J. Kochanski, Head
Shipboard Communications
Division

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1.0 INTRODUCTION

1.1 BACKGROUND

The characteristics of some antennas, e.g., input impedance (voltage standing-wave ratio (VSWR)) and pattern, are a function of the characteristics of the ship's superstructure on which they are mounted. The conductive superstructure effectively becomes a radiating element of the antenna. Currently, the Navy is investigating the use of composite materials in the construction of superstructures, deckhouses, and masts of combatant ships. The purpose is to reduce topside weight, improve structural reliability, and increase platform survivability. Composite materials are plastics, fiberglass, Kevlar®, and carbon fibers, which offer lighter weight and superior resistance to damage from bullets and bombs. However, these materials are electrically much different from the aluminum conventionally used in a ship's superstructure. A change in the conductivity of the material will greatly change the electrical characteristics of the ship's high frequency (HF) antennas, sometimes degrading performance and sometimes improving performance. The 2- to 6-MHz wire fan antenna must be supported by a metallic mast on which radio frequency (RF) currents flow. Therefore, a new design concept is required for achieving a broadband 2- to 6-MHz antenna, which can be used on ships having masts built of composite material. The first step into the solution of this problem is to design an antenna that is free-standing on a ground plane. Such an antenna corresponds to a "worst case" design, since there are no nearby metallic structures present that can be used to improve its impedance. Once the parameters (e.g., degree of conductivity) of the ship composite structures are known, this antenna design can be modified to optimize its performance. Both scale modeling and numerical modeling on computers are used extensively to design antennas. Present scale models and numerical models are adequate to develop antenna concepts useful for metallic platforms without masts. The numerical techniques to accommodate composite materials for antenna analyses are under development as part of the electromagnetic compatibility (EMC) project of the Surface Ship Technology Program (PE62121N).

1.2 SCOPE

This study addresses the task area to investigate new antenna concepts for achieving a broadband 2- to 6-MHz antenna, which can be used with ships having masts built from strong and lightweight composite materials. An earlier groundwork analysis providing the basis for the current study appears in reference 1. The development of a new antenna concept includes design of new antennas as well as development of a design/modeling methodology. The modeling methodology is as important as the antenna design since it paves the way to transition the antenna design to the Fleet. Emphasis is on the development of an antenna concept that can be used in lieu of the

HF fan antenna to provide 2- to 6-MHz HF (transmit) service and that can be used on ships with nonconductive or partially conductive masts built from composites.

To gain insight into the solution of the current problem, the antenna literature was searched for related work that has been done by others. To gain additional insight, three resistively loaded, broadband single-whip antennas independently designed and built by two private companies were tested and evaluated.

2.0 PROCEDURE

2.1 APPROACH

The following approach was used to conduct this study:

A. Perform a search of the antenna literature for related work to gain insight into the solution of the current problem.

B. Test and evaluate three broadband, single-whip antennas incorporating resistive/reactive loading that have been independently designed and built by two private companies; this will lend additional insight.

C. Perform a "Mini" Numerical Electromagnetic Code (MININEC) analysis of single-whip antennas over a ground plane. Determine the relationship between antenna length, amount and location of resistive/reactive loading, antenna feedpoint impedance (VSWR), and antenna I^2R efficiency.

D. From the trade-offs determined by the MININEC analysis, pursue other techniques that may be deemed necessary to achieve a 2- to 6-MHz transmit antenna having acceptable values for the parameters listed in step C. These techniques include dielectric coatings to shorten the necessary physical length and multiple elements to improve VSWR over the frequency band.

2.2 SPECIAL CONDITIONS

Smith Chart impedance diagrams are shown normalized to 50 ohms, except as noted. VSWR is stated relative to 50 ohms.

3.0 EXPLANATION OF RESULTS

3.1 ANTENNA LITERATURE SEARCH

A search was made into the available literature to determine the extent to which this problem had been addressed in the past. The concept of using resistive components within a whip antenna element to improve the VSWR is not new and was studied by Halpern and Mittra (reference 2) and others (references 3 and 4). Also, reference 5 and others have described the technique of resonating electrically short monopoles by adding inductors in series with the antenna element. Capacitors (i.e., capacitive loading) may also be used for this purpose. The current study seeks to find some combination of resistive/reactive elements that, when placed at some point in series with the antenna element, yield an antenna having acceptable impedance, efficiency, and physical size.

The phenomenon of antenna size reduction through dielectrically coating the element has also been explored previously. References 6 through 9 deal with this topic. The bulk of this work is theoretical, with the exception of reference 7, which presents the results of experiments performed at ultrahigh frequency (UHF) (600 MHz). However, no studies could be found that describe measurements of physical models at HF frequencies. The current study presents the results of efforts made in this area.

3.2 EVALUATION OF COMMERCIAL WHIP ANTENNAS

Three commercially designed, broadband HF whip antennas were electrically evaluated. They are

Chu Associates CA-3469 28-foot, 6- to 30-MHz
Astron Corp. SDW-201/A 25-foot, 8- to 30-MHz
Astron Corp. SDW-203/A 35-foot, 2.5- to 30-MHz

These antennas incorporate discrete circuit elements (i.e., resistors, inductors, and/or capacitors) within the actual antenna radiating element to achieve a VSWR within about 3:1 over their respective design frequency bands. The resistors are an essential part of the design and provide the loss necessary to achieve a good impedance match at the lowest frequencies in the design frequency bands. The trade-off is that this necessarily results in a corresponding loss of antenna efficiency at those frequencies and a high heating effect in the resistors, which can cause the antenna to fail under high RF power application if the resistors are not adequately heat-sinked.

Note that these antennas were designed as possible replacements for the existing shipboard 35-foot whip and AN/URA-38 tuner/coupler 2- to 30-MHz system, which has only one 1-kW transmitter feeding it at a time. A broadband antenna to replace this

existing system is desirable because it does not need to be tuned to each selected operating frequency, making it more convenient to use. The lack of moving parts should make it more reliable than the existing whip/coupler, and, since no tuning is necessary, it can also be used in frequency-hopping antijam systems. Note, however, that the current task is to find a replacement for the twin fan antenna which can be used to provide 2- to 6-MHz transmit service on future ships using composite materials that might render a working twin fan design impossible. Although this might seem to be a simpler problem due to the smaller frequency span, it is actually much more difficult for two reasons:

A. The whip/coupler is less efficient over 2 to 6 MHz than the twin fan and its matching network due to the inherently greater loss in the coupler's matching elements.

B. The twin fan is capable of dissipating 5 to 10 kW of RF power from the multiple transmitters that feed it via a multicoupler.

In addition, it is much simpler to design a physically small HF antenna that works down to 2.5 MHz than one which goes all the way down to 2 MHz. The antenna must be 1.25 times as large at 2 MHz than at 2.5 MHz to achieve a similar efficiency because of the correspondingly larger electrical wavelength at 2 MHz.

The analysis of the commercially produced antennas was deemed useful to provide insight into the solution of the current antenna design problem. As a result of the broadband whip antenna evaluation, the following conclusions were made:

A. The impedances of each antenna (measured prior to high-power application) agreed well with those obtained and published by the manufacturers. The Chu antenna VSWR was within 3.3:1 over 5.46 to 30 MHz. The Astron 25-foot antenna VSWR was within about 3.1:1 over 8 to 30 MHz. The Astron 35-foot antenna VSWR was within about 3.3:1 over 2.5 to 30 MHz.

B. Gain measurements made between each antenna and an 18-foot whip antenna located 121 feet away yielded the following results: the Chu gain (measured prior to high-power testing) was within about −7 and +9 dB of that measured for a 35-foot whip tuned at each of several frequencies over 6 to 30 MHz using an AN/URA-38 tuner/coupler and an AN/URT-23D transmitter. The Astron 25-foot gain was within about ± 8 dB of that of the 35-foot whip/coupler over 8 to 30 MHz. The Astron 35-foot gain was lower than that of the whip/coupler over 2.5 to 30 MHz, with the lowest gain occurring at 2.5 MHz, where it was 17 dB below that of the whip/coupler. This drop-off in gain is due to a concurrent drop-off in antenna efficiency, probably caused by the high amount of resistive loss necessary to achieve a 3:1 VSWR at that frequency.

C. Both the Chu 28-foot and the Astron 25-foot antennas survived 1-hour applications of approximately 1000 watts of RF input power at each of several frequencies over their respective operating frequency bands. The Astron 2.5- to 30-MHz 35-foot

broadband antenna did not survive the power-handling test. The antenna VSWR was permanently increased by the test, probably due to the failure of circuit components within the antenna because of inadequate heat-sinking.

The VSWR/gain trade-off was borne out by the MININEC study, described in the next section. A complete report of the broadband HF whip evaluation is given in Naval Ocean Systems Center (NOSC) Technical Note 1651, February 1991.*

3.3 MININEC STUDY

A MININEC study was made to determine whether a single-whip antenna over a ground plane can be loaded with complex (resistive/reactive) circuit elements to yield a VSWR within about 3:1 over 2 to 6 MHz, without excessively decreasing the antenna efficiency over the frequency range. If such an antenna could be designed, it may be possible to mount it on a ship in such a location that the resulting impedance is at least as good as that obtained over a ground plane. Such an antenna could be used on ships having either metallic or composite material superstructures. Composite materials would affect the antenna impedance to a lesser degree than metallic materials and would yield results tending toward those obtained for the ground plane design. On the other hand, nearby metallic structures would not necessarily be detrimental to the antenna impedance, but could probably be used to advantage through judicious antenna placement. An additional advantage of the single-whip, ground-plane analysis is that its inherent simplicity makes it easy to handle using MININEC, which can be run on a personal computer (PC). Although Numerical Electromagnetic Code (NEC) can be used for more complex geometries that exceed the MININEC capacity, NEC is more complex and time-consuming to run.

Several cases were run to quantify the trade-off between antenna impedance (VSWR) and efficiency for different physical lengths and circuit loading. It quickly became obvious that inductive-capacitive loading alone is not sufficient to achieve an acceptable VSWR (approximately 3:1) over 2 to 6 MHz with a whip of any reasonable length, say, 12 meters; resistive loading must also be used. The use of resistors has a broadbanding effect on the structure, allowing a good VSWR over 2 to 6 MHz with an antenna that is physically much shorter than would otherwise be possible. Unfortunately, this results in reduced antenna efficiency due to the power lost in the resistors. These effects have been previously noted by others, notably, Halpern and Mittra (reference 2).

To illustrate the trade-off between loading (hence, VSWR) and efficiency, the results of several MININEC calculations follow. Note that the efficiency refers to the radiation (I^2R) efficiency, where

* "Electrical Evaluation of Broadband HF Whip Antennas; Chu CA-3469 28-Ft 6- to 30-MHz, Astron SDW-201/A 25-Ft 8- to 30-MHz, Astron SDW-203/A 35-Ft 2.5- to 30-MHz," by Y. C. Wire and R. S. Abramo. NOSC Technical Notes are working documents and do not represent an official policy statement of NOSC. For further information, contact the author.

$$n_{rad} = P_{rad}/P_{in} \times 100\%$$

$$P_{rad} = P_{in} - I^2R$$

n_{rad} : radiation efficiency

P_{rad} : antenna radiated power

P_{in} : antenna input power

R : equivalent series resistance of load

I : current through equivalent series resistance

It is seen from this that for an ideal (lossless) unloaded structure, the radiation efficiency equals 100 percent; it is the addition of the resistive component that decreases the efficiency. When parallel resistive/reactive (RLC) loading is used, care must be taken in calculating R and I. The use of complex loading improves the VSWR over the frequency band, compared with purely resistive loading (reference 2, p. 44); this was verified in the current MININEC study. Note also that the radiation efficiency is independent of the characteristic impedance of the transmission line that feeds the antenna. An overall system efficiency can also be calculated that takes this into account, but is not done here; since our VSWR goal is similar to that of existing antennas, the mismatch correction will also be similar. Therefore, the radiation efficiency of our final antenna designs offers a good measure of comparison with the (nearly) 100-percent efficient existing antennas.

The first case we present here is that of a 12-meter-long monopole with a 200-ohm purely resistive load placed across the feedpoint. Since the equivalent circuit of the resulting structure is a 200-ohm resistor in parallel with the antenna impedance, one would expect the resulting impedance to exhibit a VSWR within 4:1 over the band (2 to 6 MHz), referenced to 50 ohms. Indeed, the MININEC results confirm this and are as follows:

Trial #1:	Freq (MHz)	VSWR| 50 ohms	Eff (%)
200-ohm resistor	2	4:1	0.1
across feed of	4	4:1	9.1
12-m monopole	6	1.6:1	84.0

It is seen from this that, while it is easy to achieve a low VSWR using this method, the resulting efficiency becomes extremely small at the low end of the band. Furthermore, the efficiency can only be increased by choosing a resistance value that yields a higher VSWR. Therefore, this method cannot be used to produce a useful antenna design. Placement of the resistive loading at other points along the antenna does not improve the results significantly; the use of complex RLC loading was, therefore, considered.

Halpern and Mittra (reference 2) suggest that a 12-meter whip can be loaded with a parallel RLC network at 3.3 m above the feedpoint to provide a good impedance match to 250 ohms (meaning that a 5:1 impedance transformer can be used for a 50-ohm system). Note that the Halpern and Mittra design is intended to work over 2 to 30 MHz and sacrifices some VSWR at the 2-MHz end of the band. Figure A-1,* reprinted from reference 2, shows a schematic of this antenna design. The computed impedance for this antenna relative to 250 ohms is given in figure A-2, also reprinted from reference 2. The current analysis used an antenna diameter of 15.2 cm vice the 15 cm used in reference 2; this did not appreciably affect the final results. When this case was run on MININEC, the following results were obtained:

Trial #2:	Freq (MHz)	VSWR| 50 ohms	VSWR| 250 ohms	Eff (%)
H&M 12-m monopole	2	35:1	9.7:1	2.8
par. RLC 3.3 m	4	9.5:1	3.6:1	8.1
above feed	6	4.5:1	2.8:1	22.1
R=240 ohm				
L=20 uH				
C=100 pF				

These results agree well with those of reference 2 for the same case. They show that with complex loading the efficiency at the 2-MHz end of the band is improved compared to that obtained with purely resistive loading, but at some expense to the efficiency at the high end of the band.

An electrical matching network was then found, which, in combination with an RF transformer, yields a VSWR within 3:1 over 2 to 6 MHz. It was found that a 200:50-ohm (4:1) transformer must be used (rather than the 250:50-ohm transformer used by Halpern and Mittra) to obtain the desired VSWR. The resulting impedance over 2 to 6 MHz, along with the matching network and transformer used, appear in figure A-3. The radiation efficiency is not affected by the addition of the ideal (lossless) matching network and transformer.

A number of complex-loaded 12-meter cases were tried, but no appreciable improvement in efficiency over 2 to 6 MHz could be found over the Halpern and Mittra case. Reference 2 also considered the use of two complex loads in a 12-meter antenna to improve the VSWR and efficiency over 2 to 30 MHz. This antenna schematic and its computed input impedance relative to 250 ohms appear in figures A-4 and A-5, respectively (reprinted from reference 2). The chief benefit of this design was an improved VSWR over about 6 to 30 MHz compared with the single complex load case; however, 2 to 6 MHz actually had a higher VSWR, which accounts for the higher efficiencies achieved at those frequencies. An effort was made to use MININEC to

* Figures are placed in appendix A.

optimize this design over 2 to 6 MHz, but no matching network/transformer combination could be found that yielded a VSWR within 3:1 over that frequency range using the Halpern and Mittra loading. The use of multiple loads does not appear to have any great advantage in the design of a 2- to 6-MHz antenna. Nonetheless, this will be investigated further when loading and dielectric coating techniques are later combined to achieve a final antenna design.

From the foregoing results, we concluded that it is probably necessary to increase the antenna element length to achieve a significant further improvement in efficiency for a given VSWR. The antenna length was doubled, and the same loading as used in trial #2 was placed at twice the previous distance from the feedpoint (6.6 meters). The MININEC results for the resulting 24-meter-long complex-loaded monopole are as follows:

Trial #3:	Freq (MHz)	VSWR| 50 ohms	VSWR| 250 ohms	Eff (%)
24-m mono. par	2	5:1	2.3:1	9.9
RLC 6.6 m above	4	5.5:1	1.5:1	25.0
feed	6	9:1	2.5:1	53.0
R=240 ohm				
L=20 uH				
C=100 pF				

The foregoing results illustrate the necessity of increasing the antenna element length to obtain a significant increase in efficiency over 2 to 6 MHz. Since an efficiency goal of at least 50 percent across the band is desirable, we see that the use of circuit-element loading alone would require an element length significantly greater than 24 meters (78 feet 9 inches). Such lengths would be quite impractical! Therefore, unless a significant loss in efficiency can be tolerated, compared to the existing (twin fan) antenna for which a replacement is being sought, some other method must be employed to achieve the desired results, either in combination with the circuit loading technique or in place of it. The use of an antenna with an efficiency that is 10 percent of the twin fan's efficiency at any frequency will result in a greatly decreased communication range at that frequency.

For these reasons, the technique of surrounding the antenna element with a dielectric material to increase its electrical length was then considered. We hoped this would increase the efficiency over the 2- to 6-MHz frequency range.

3.4 PHYSICAL MODEL STUDY OF DIELECTRIC MATERIAL EFFECTS ON ANTENNA RESONANT FREQUENCY

An investigation was made into lowering the resonant frequency of a whip antenna by coating it with dielectric material. Magnetic material could also be used for this

purpose, either alone or in combination with dielectric material, but was not considered in this study. This technique slows the phase velocity of the electromagnetic wave traveling along the antenna, making it electrically longer. This happens because the phase velocity in any medium is inversely proportional to the square root of the product of the permittivity (dielectric constant) and the permeability; dielectric or magnetic materials have higher values for these constants than does air. As stated in section 3.1, a search of the literature revealed no prior work with physical models at HF to quantify this effect.

Two physical models were built; figure A-6 is a photo showing the author with both models. The models consisted of (approximately) 10-foot-long PVC and ABS plastic tubes of 2-inch (PVC) and 4-inch (ABS) inner diameters (IDs). Down the center of each tube was supported a length of lightweight fan antenna (LWCA) cable, which is a plastic-coated multiple-strand phosphor bronze wire having a nominal overall conductor diameter of about 0.3 inch. The total length of cable used for each model was about 13 feet. The tubes were sealable at each end so they could contain liquid dielectric material without leaking. A bare piece of fan antenna cable of similar length to that used in the models was measured to have an "uncoated" standard of reference (neglecting the effect of its relatively thin plastic coating). Water, with a dielectric constant of approximately 80 (at HF), was chosen as the "filling" for the models. Distilled water initially was used, but tap water was found to yield similar results for the 2-inch model and was subsequently used for the 4-inch model.

Impedance, VSWR, and gain (transmission loss) of the bare cable and the two models (air- and water-filled) oriented vertically over a ground plane were measured over 1 to 31 MHz with a Hewlett-Packard (HP) 8753C RF Network Analyzer. Gain was measured between each test antenna and an 18-foot whip antenna located 121 feet away. The gain is the negative of the total transmission loss between the two antennas (the space loss between the antennas plus the two antenna mismatch losses). Figures A-7 through A-9 show the impedance, VSWR, and gain plots for the bare cable. Its resonant frequency was 19.801 MHz and the gain at resonance was about –29 dB. Figures A-10 through A-12 show that the 2-inch tube containing a similar cable had a slightly lower resonant frequency of 19.057 MHz; the gain at resonance was about –28 dB. The gain curve was similar to that of the bare cable. Figures A-13 through A-15 show that filling this tube with water shifted the resonant frequency downward to 15.934 MHz; this corresponds to about a 16-percent reduction in resonant frequency. The gain at the new resonance frequency was still about –29 dB.

A theoretical analysis was then done to predict the results for a different diameter of dielectric material surrounding the antenna cable. For the analysis, dual concentric capacitors were considered, and an effective dielectric constant for the combination of the coating material and the air between the coating and the ground plane was

calculated by letting the outer conductor approach the ground plane and approximating the average distance between the inner and outer conductors as one-half the antenna length (5 feet). This analysis predicted a resonant frequency of 15.5 MHz for the 2-inch water-filled tube; this is close to the measured value of 15.934 MHz. A correction factor was calculated from this and was used to predict the resonant frequency of a 4-inch water-filled tube as 14.68 MHz.

A 4-inch tube was then used to construct another model whose other dimensions were similar to those of the 2-inch-diameter model. Figures A-16 through A-18 show the measured results for the air-filled 4-inch tube. Its resonant frequency was 20.126 MHz and its gain at resonance was about −30 dB. Figures A-19 through A-21 show the results of measurements made with this antenna filled with water. The new resonance frequency was 14.591 MHz. This compares well with the predicted value of 14.68 MHz and represents a 27.5-percent reduction in resonant frequency from the air-filled case. The gain of the water-filled antenna was about −29 dB at 14.591 MHz.

The foregoing measurements demonstrate that the technique of dielectric coating can be used to lower the resonant frequency of an antenna. An observation of the Smith Chart impedance plots shows that this technique raises the antenna Q somewhat, making the antenna less broadband; however, this effect does not appear to be large enough to hinder the technique's usefulness in the current design effort. Since the measured gains did not decrease when the antennas were coated, it is probable that the efficiency was also relatively unaffected; a change in radiation pattern shape due to the increased electrical length could affect this somewhat, but was not considered in this analysis.

Further calculations using the theoretical analysis indicate that widely varying the dielectric constant (4-inch-tube case) results in very little change in effective dielectric constant for the dielectric/air medium between the metallic antenna radiating element and ground. This seems reasonable because the air comprises a much greater proportion of the total path than the dielectric coating. Dielectric constants for the coating varied between 41 (ethylene glycol) and 1143 (barium titanate) and resulted in calculated effective dielectric constants between 1.66 and 1.69. It may be concluded that a practical material for use in an actual antenna should have a dielectric constant of at least about 40 and be chosen to have the lightest possible weight and stability with temperature variations. The choice of material is left for future study.

4.0 CONCLUSIONS

As a result of this study, three conclusions were made.

A. Several commercially designed whip antennas incorporating resistive and/or reactive circuit loading were evaluated. Although the impedance of one of these antennas (a 35-foot loaded whip) exhibited an acceptable (approximately 3:1 or less) VSWR down to 2.5 MHz, its efficiency dropped off considerably at its lowest design frequencies due to the resistive loading necessary to achieve the VSWR. This antenna also did not withstand high-power testing. The amount of resistive loading necessary to extend the operating frequency down to 2 MHz for an antenna of this length would likely accentuate these problems.

B. MININEC calculations for a 12-meter whip with complex (resistive/reactive) circuit loading support the conclusion that too much efficiency must be sacrificed for an antenna of this physical length to achieve an acceptable VSWR (3:1) down to 2 MHz.

C. An investigation into the reduction of antenna physical length by surrounding it with dielectric material resulted in about a 27-percent reduction in resonant frequency. This yields a significantly shorter antenna for a given frequency of operation. Dielectric coating may be usable in conjunction with complex circuit loading and multiple elements to achieve an acceptable VSWR and efficiency over 2 to 6 MHz.

5.0 RECOMMENDATIONS

The techniques of dielectric coating, complex loading, and multiple elements can now be combined to design an acceptable 2- to 6-MHz transmit antenna. MININEC should be used to design a complex-loaded antenna having greater physical length, and, hence, higher efficiency than the 12-meter length considered thus far. The physical length can then be decreased through the use of dielectric coating. A new computer code from the University of Houston that can consider dielectric and magnetic material coatings will be used to help solve this problem. If necessary, multiple elements can also be used to further improve the VSWR over the whole band. Once an acceptable design is achieved, an engineering model can be built and tested.

6.0 REFERENCES

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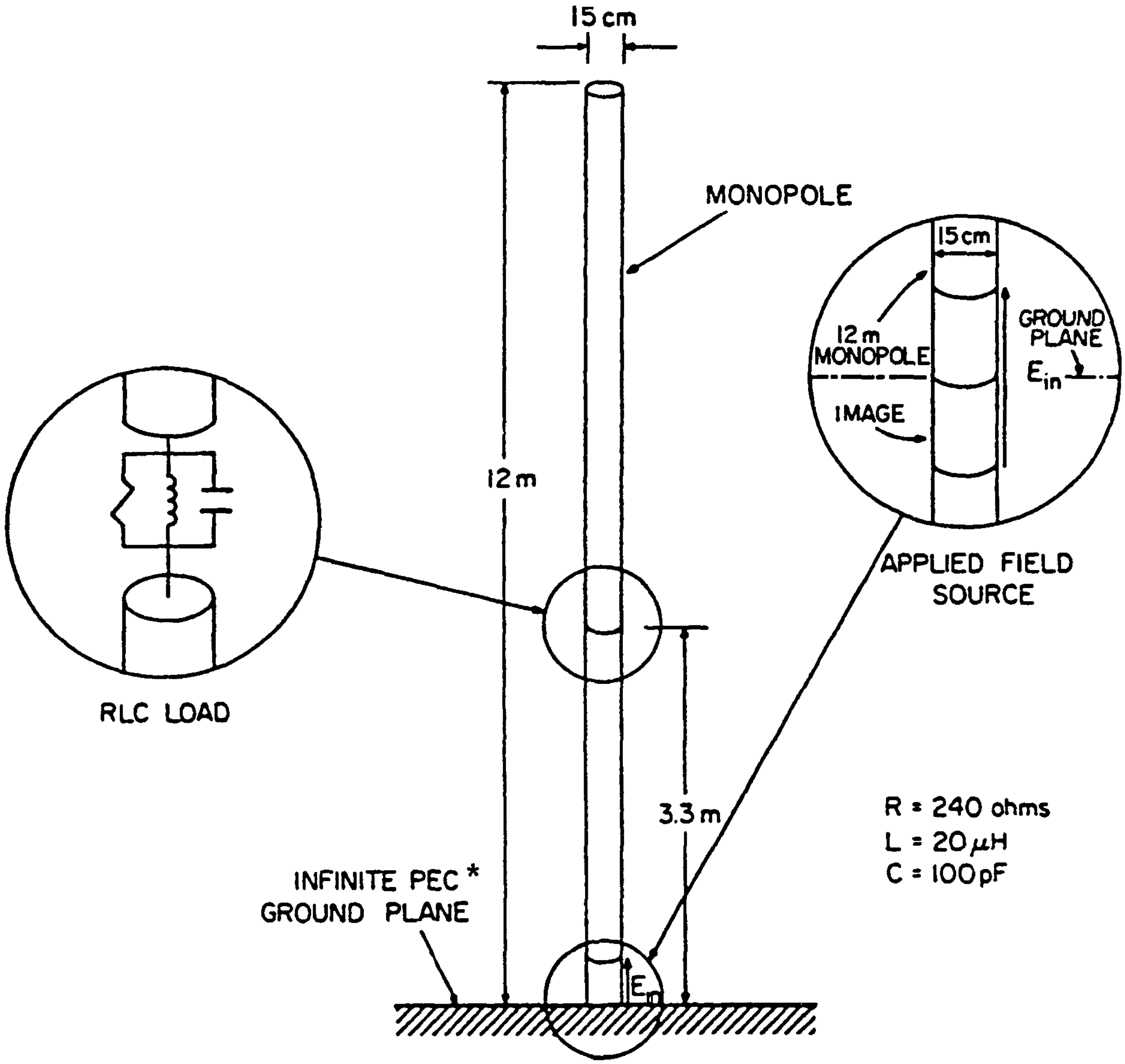
* These two documents had limited distribution. For further information, contact the author.

APPENDIX A

ILLUSTRATIONS OF ANTENNA IMPEDANCE, VSWR, AND GAIN



*PERFECT ELECTRICALLY CONDUCTING

Figure A-1. Twelve-meter antenna with single complex RLC load (reprinted from reference 2).

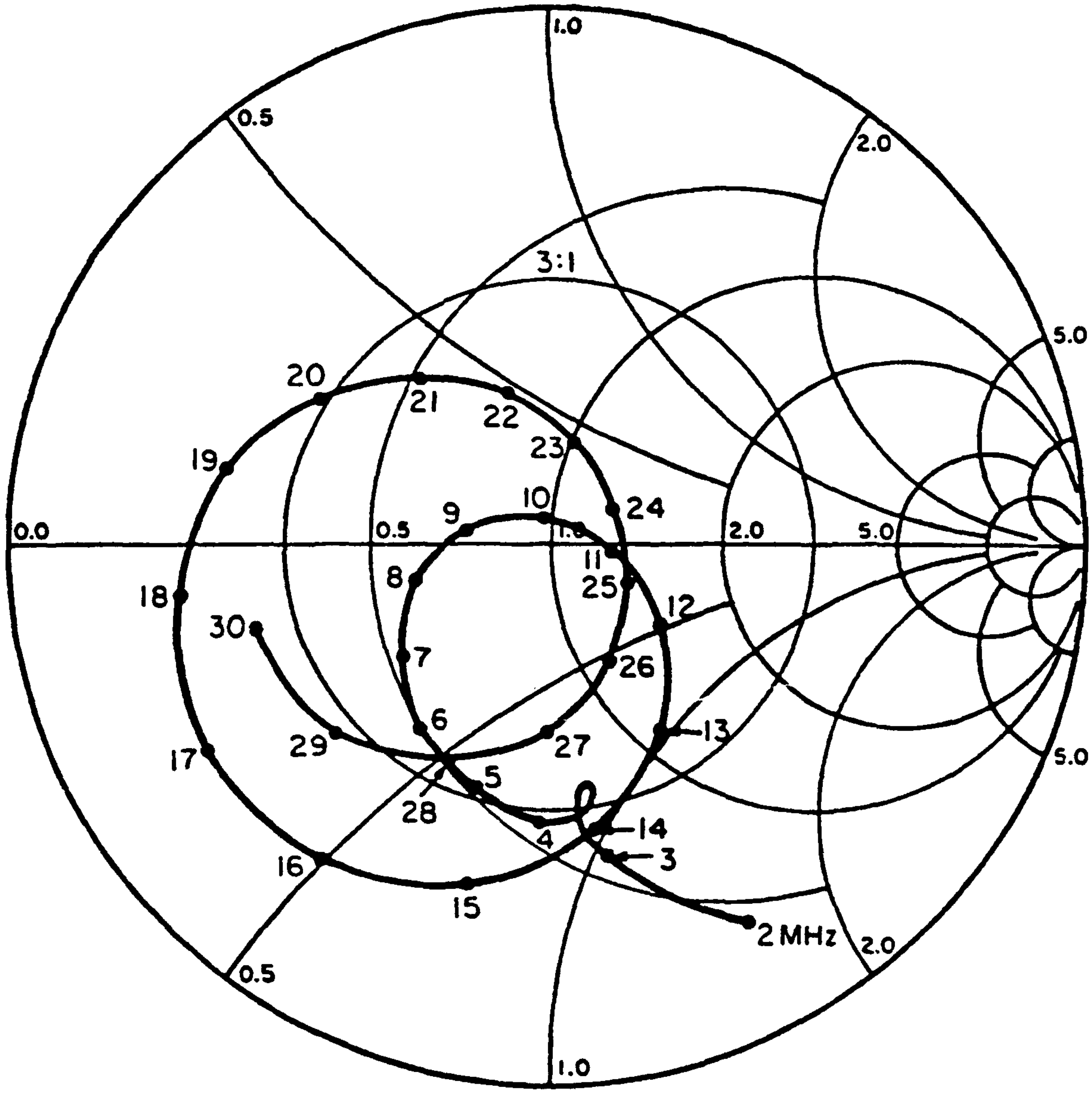
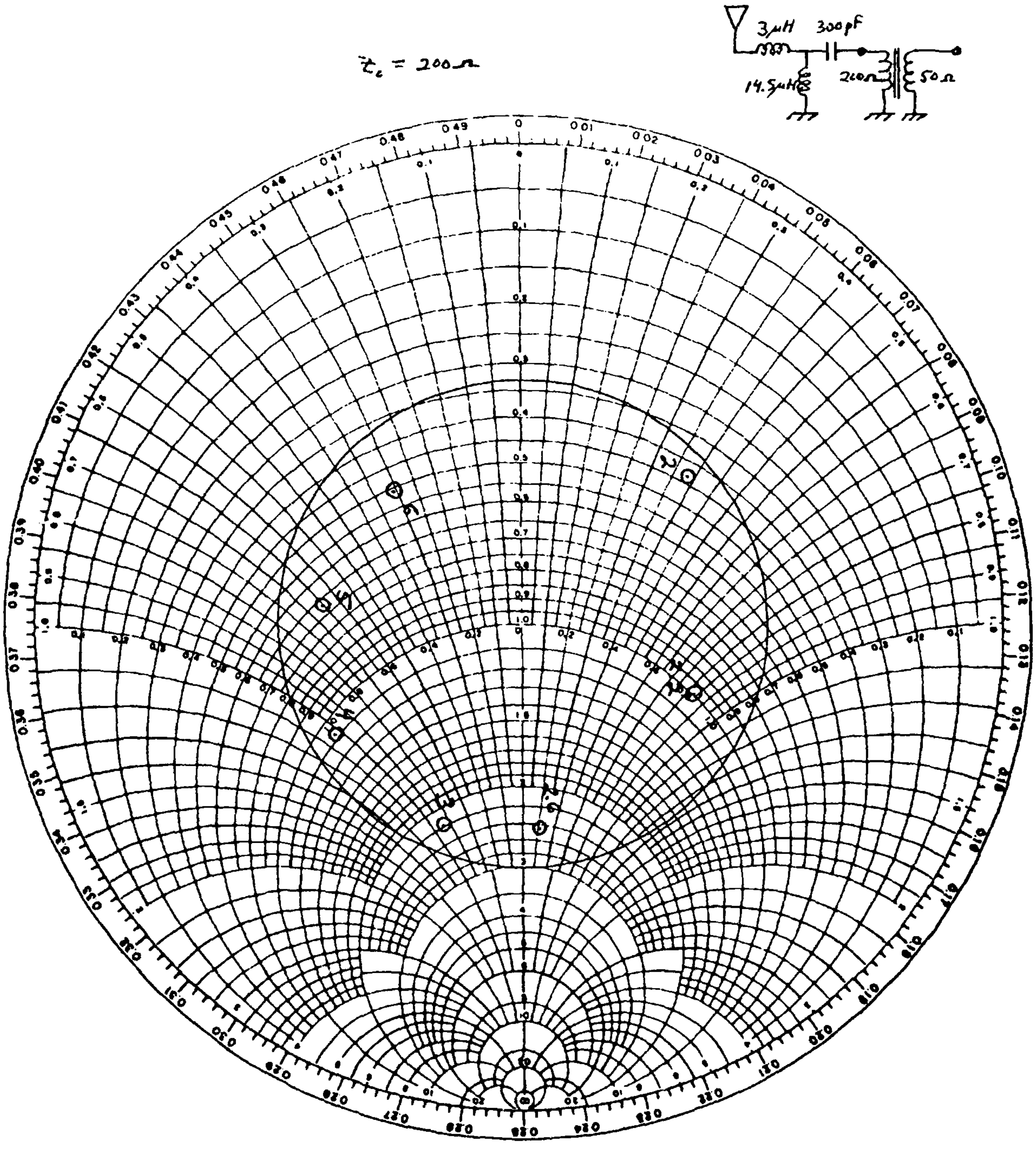


Figure A-2. Computer input impedance of the antenna of figure A-1 (reprinted from reference 2).



VSWR: 3

Figure A-3. Input impedance of the antenna of figure A-1 with matching network and RF transformer.

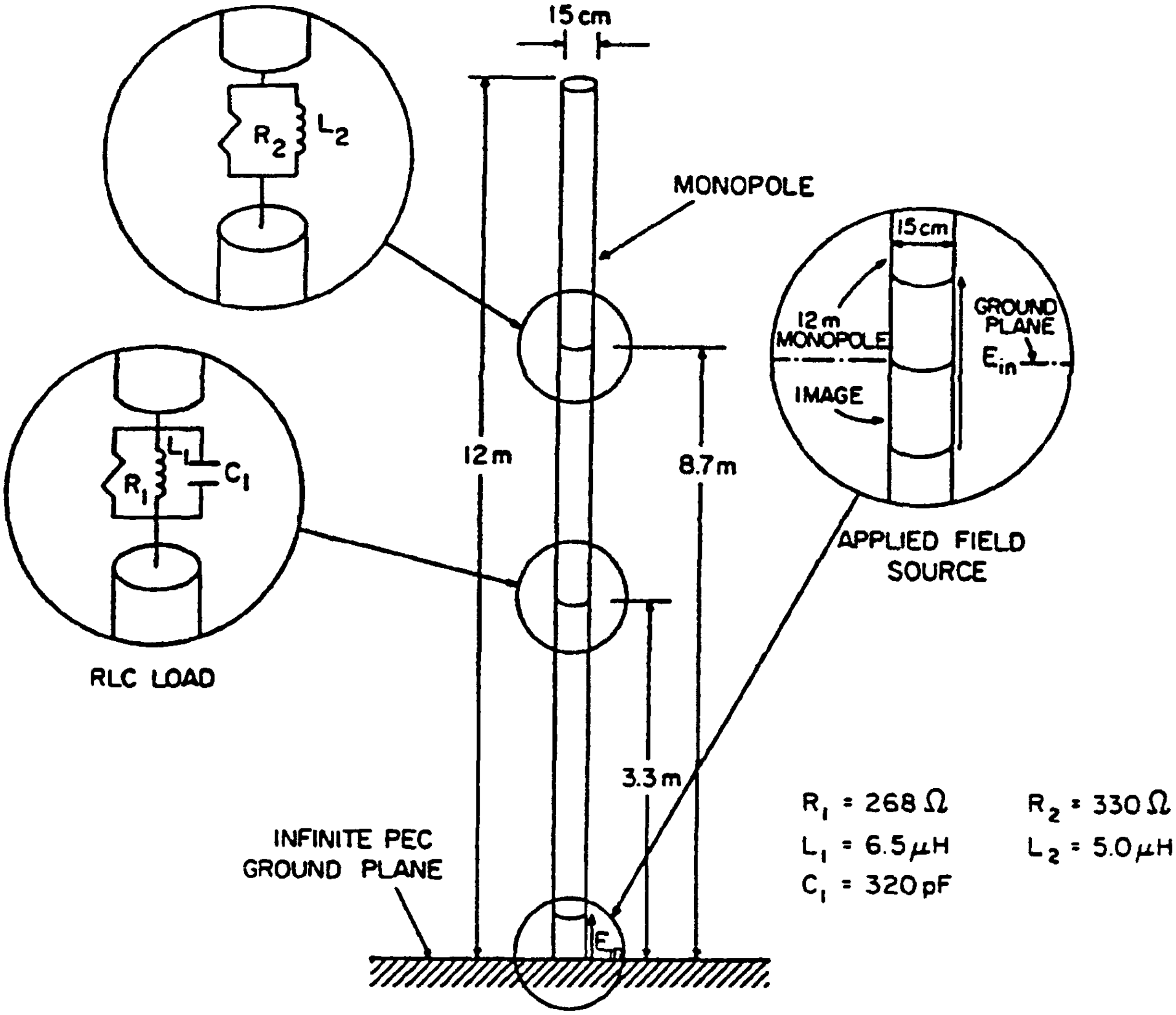


Figure A-4. Twelve-meter whip antenna with two complex RLC loads (reprinted from reference 2).

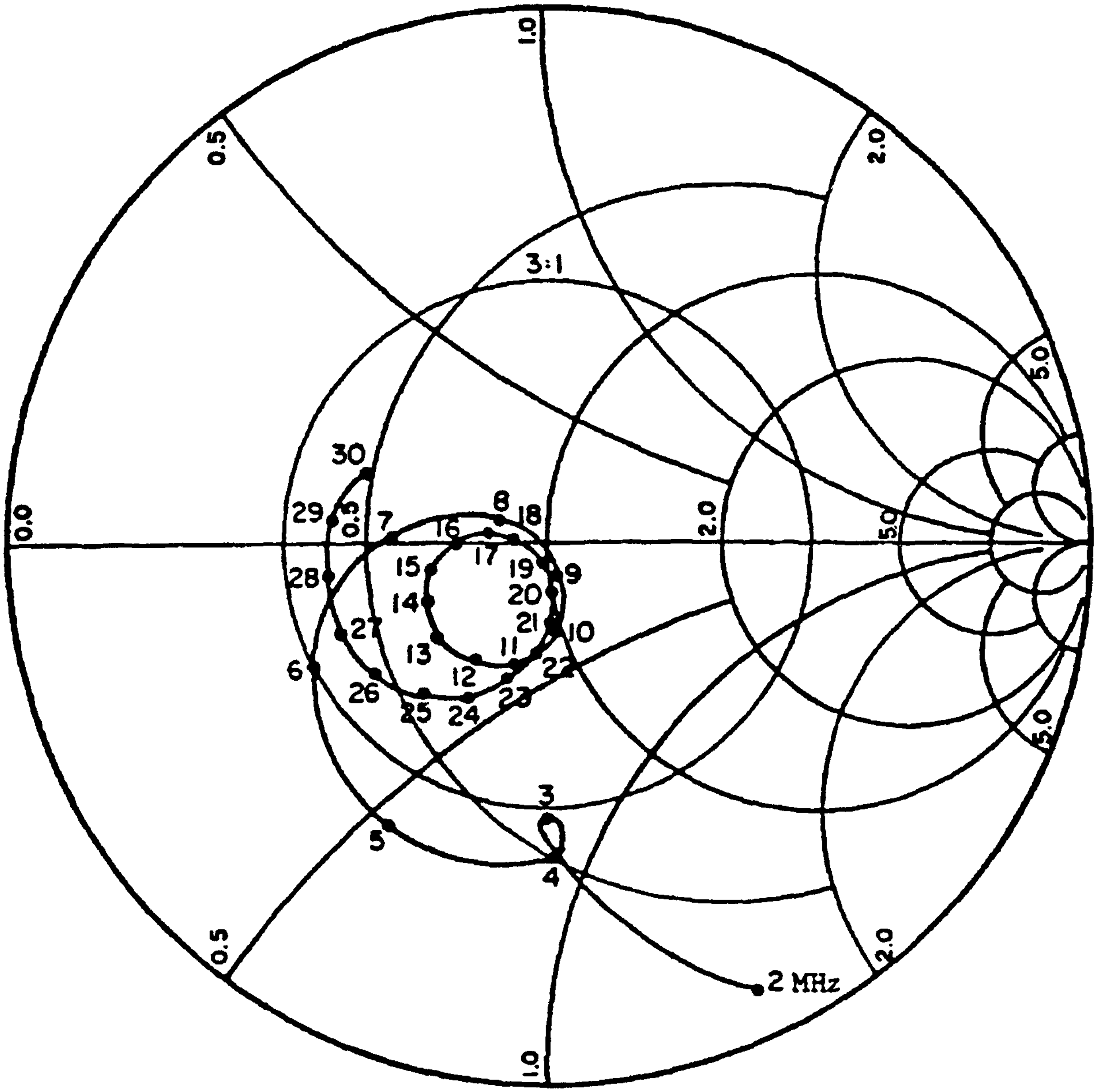
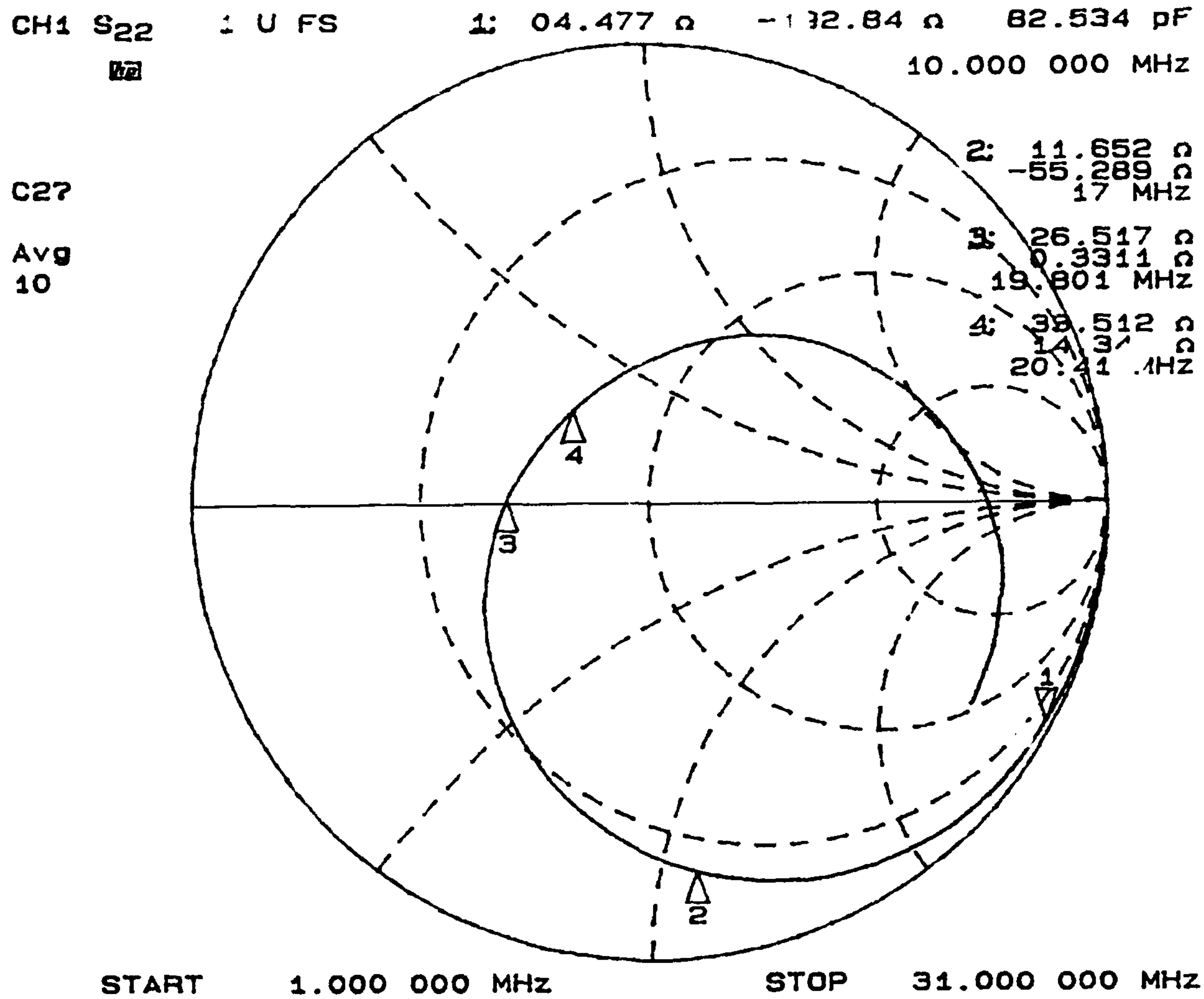


Figure A-5. Computer input impedance of the antenna of figure A-4 (reprinted from reference 2).

Figure A-6. Author showing two physical models used for dielectric coating measurements.



10'9" VERTICAL LWCA CABLE (TOTAL LENGTH = 13')

Figure A-7. Impedance of bare lightweight fan cable vertical over ground.

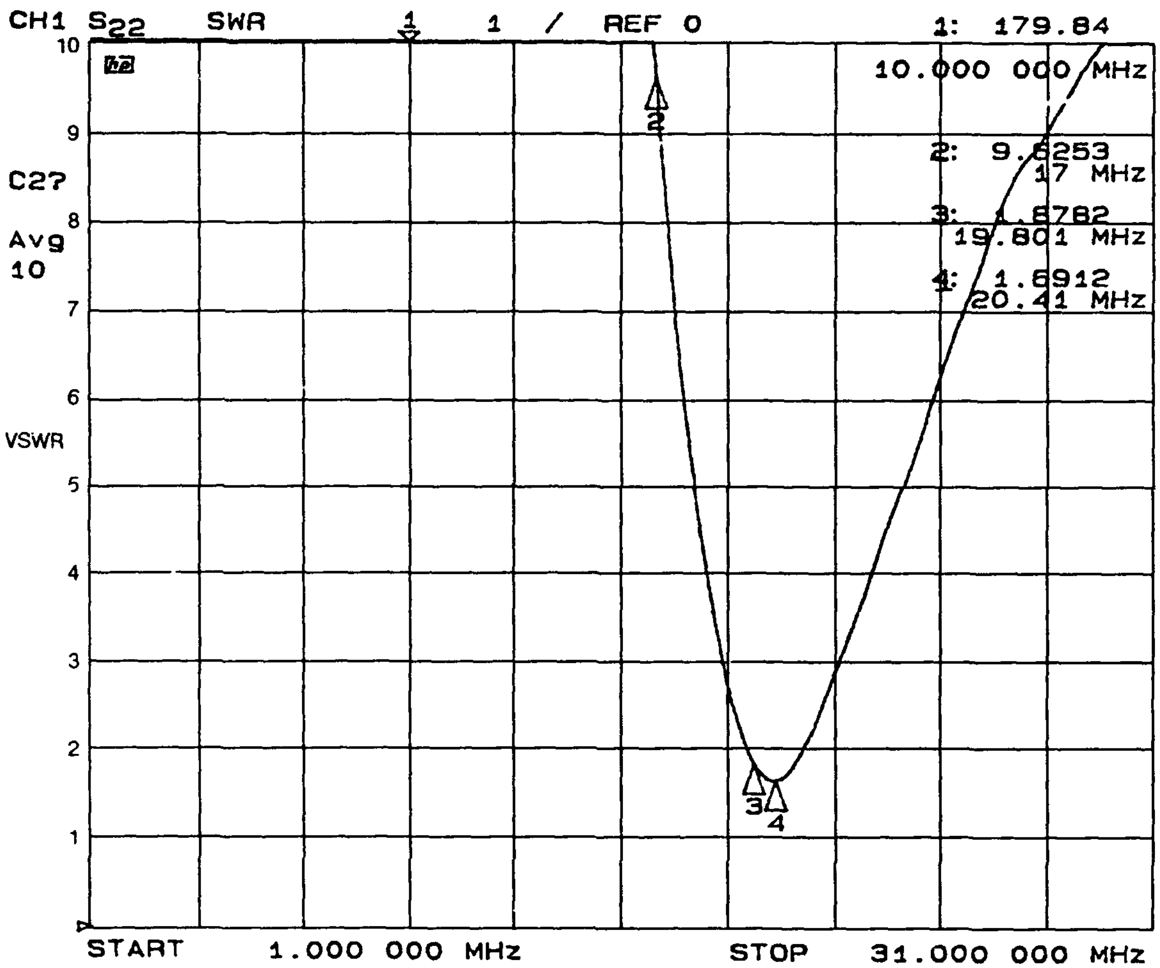


Figure A-8. VSWR (antenna of figure A-7) of bare lightweight fan cable vertical over ground.

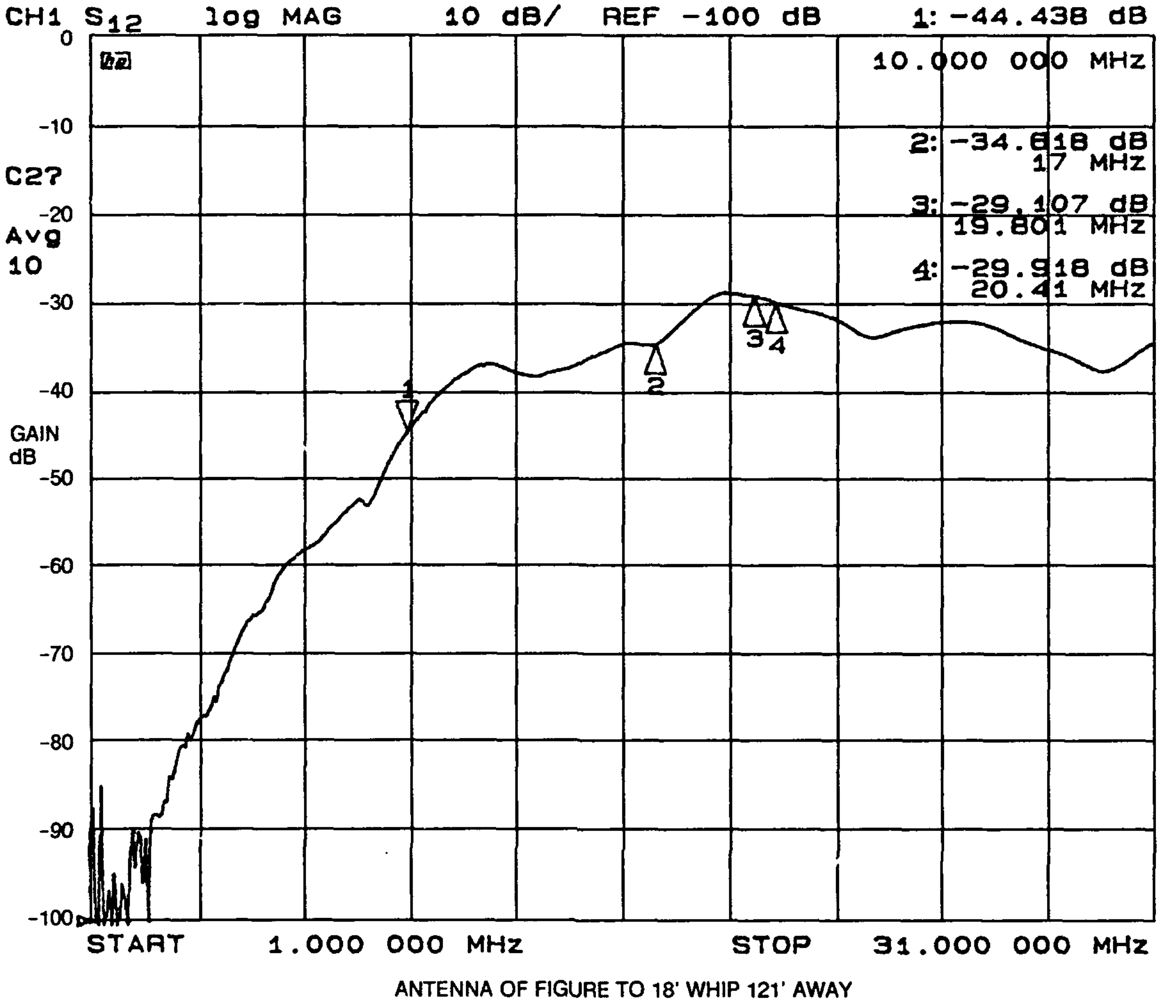
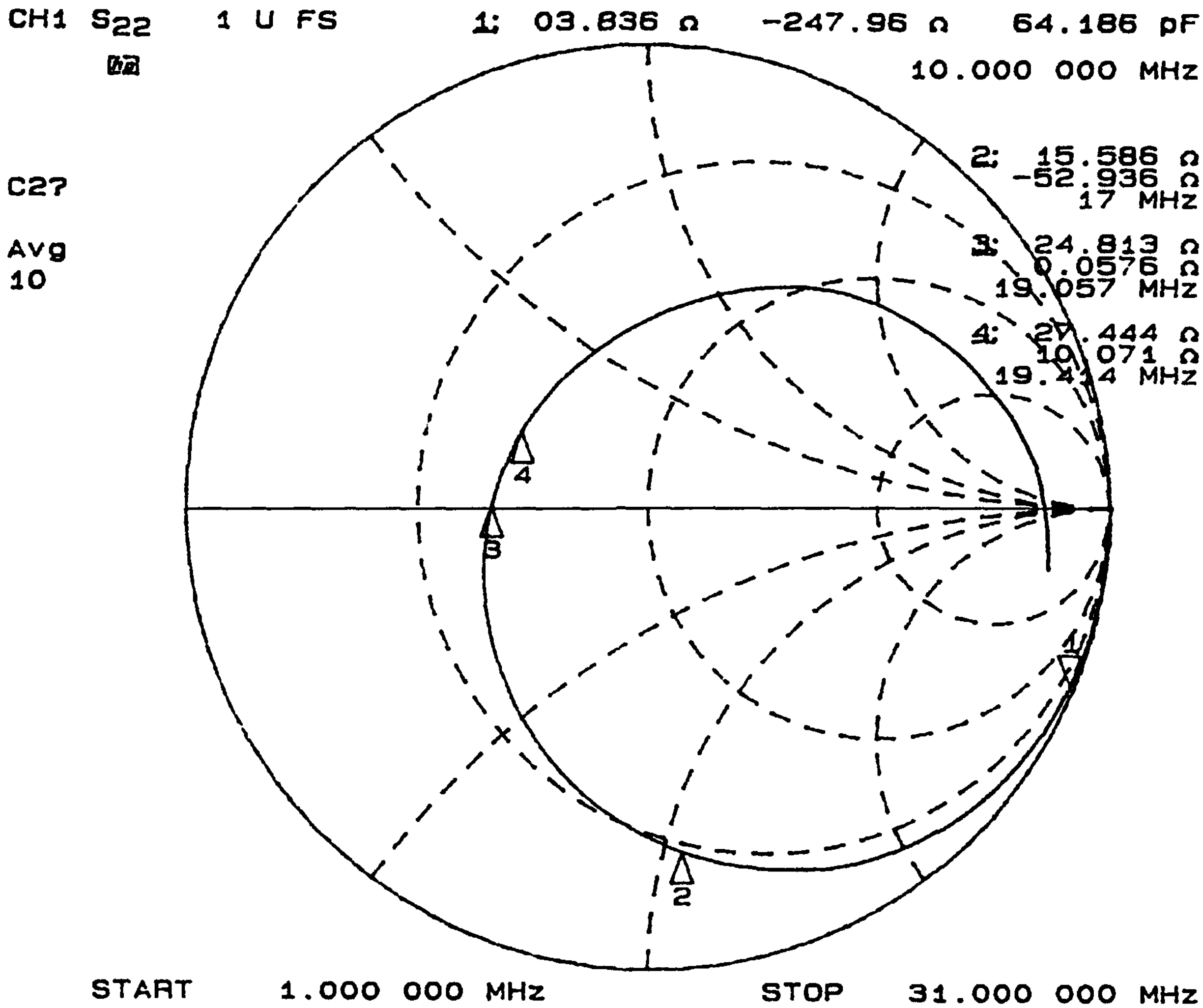


Figure A-9. Gain (antenna of figure A-7) of bare lightweight fan cable vertical over ground.



10'5" LWCA CABLE IN PVC TUBE + 4" BARE CABLE (VERTICAL)
2" I.D. PVC (TOTAL CABLE LENGTH = 13')
DIELECTRIC = AIR BETWEEN CABLE AND TUBE

Figure A-10. Impedance of air-filled, 2-inch ID antenna.

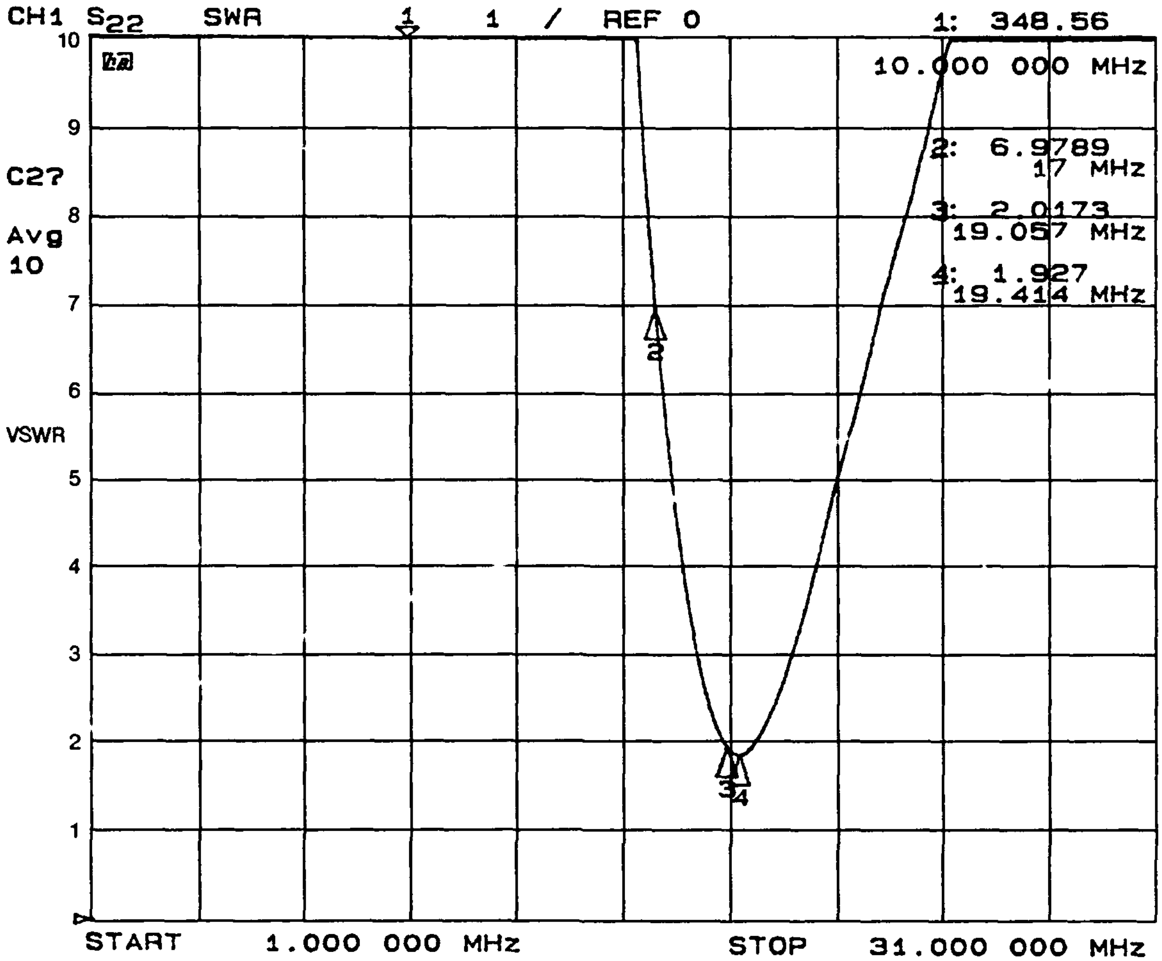


Figure A-11. VSWR (antenna of figure A-10) of air-filled, 2-inch ID antenna.

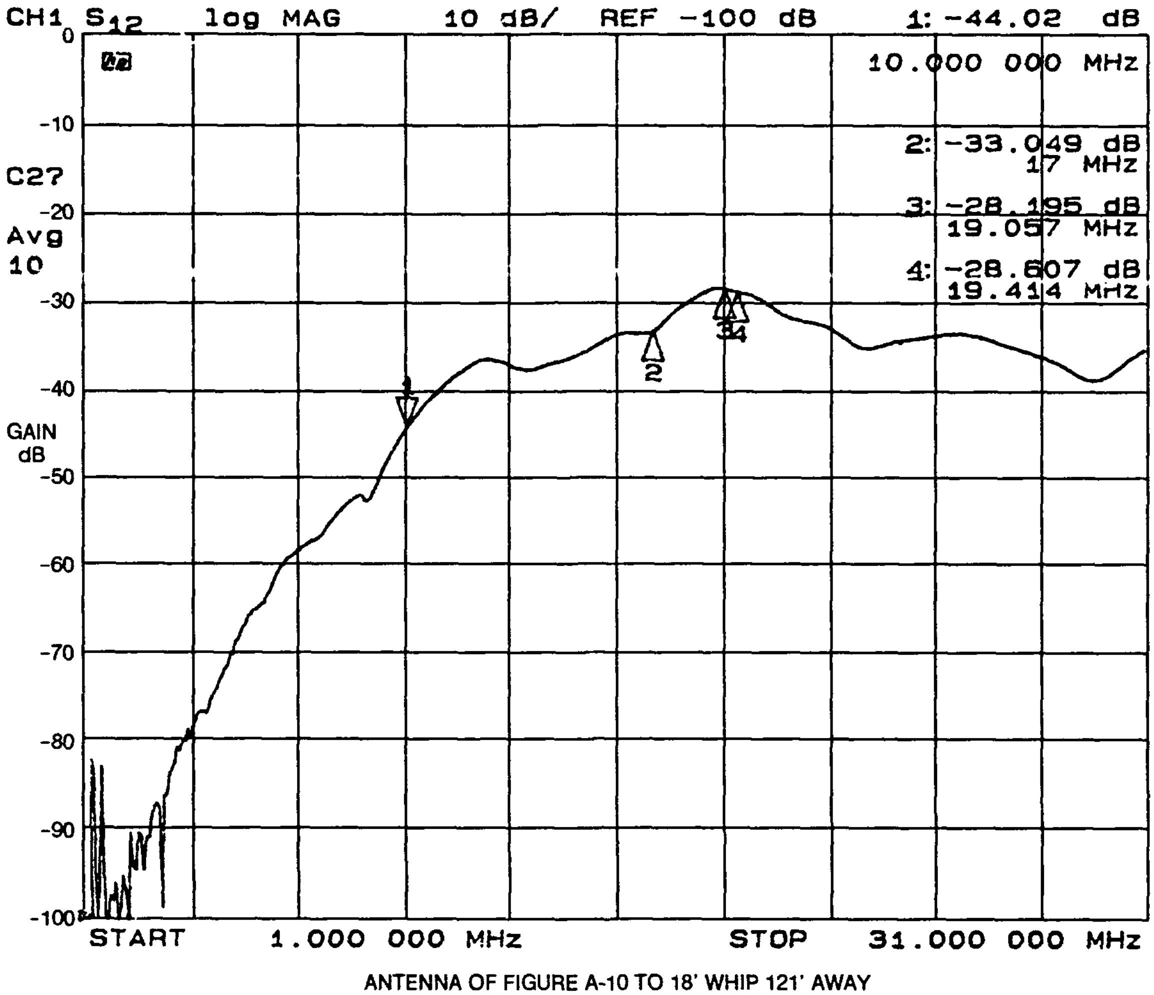


Figure A-12. Gain (antenna of figure A-10) of air-filled, 2-inch ID antenna.

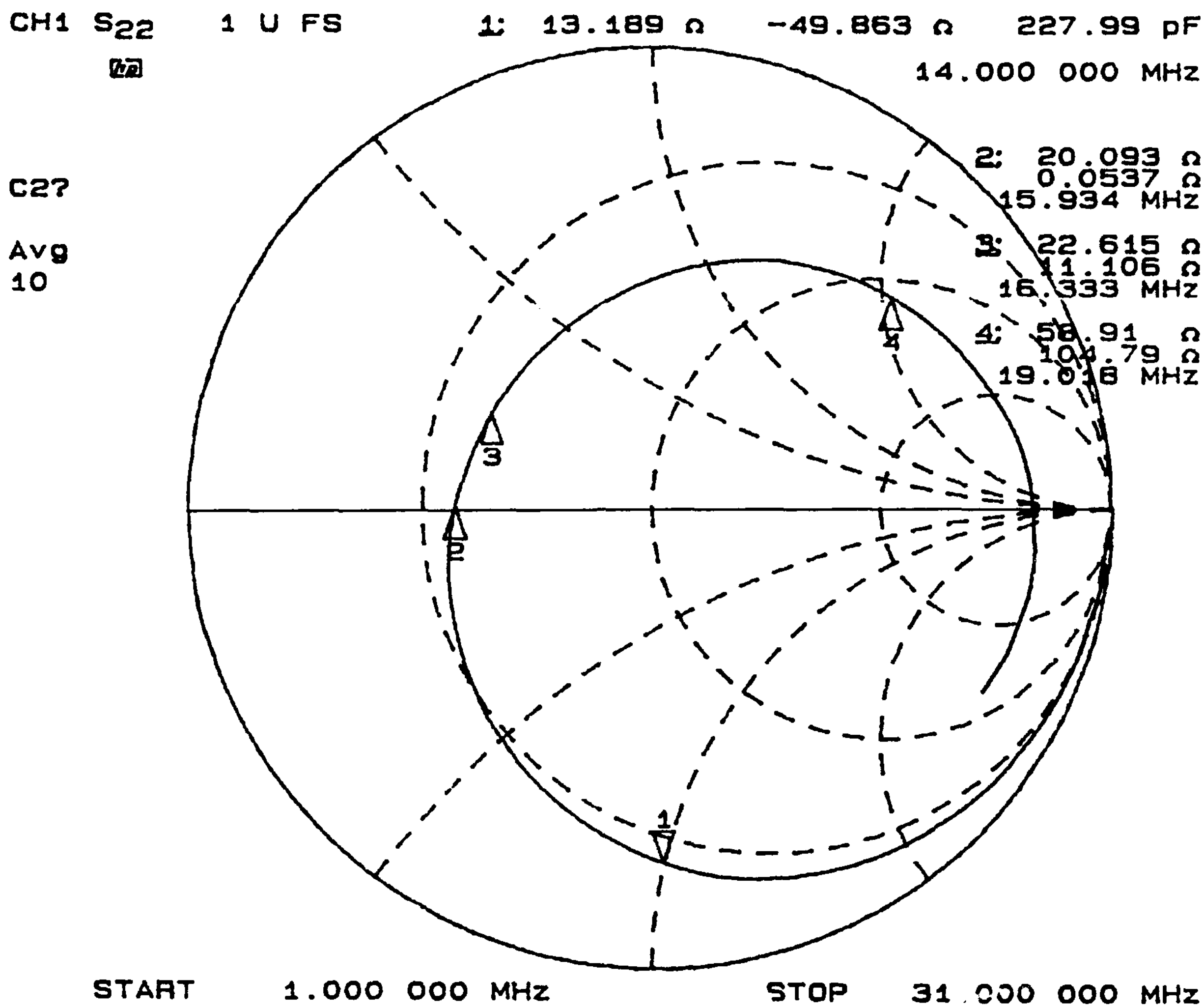


Figure A-13. Impedance of water-filled, 2-inch ID antenna.

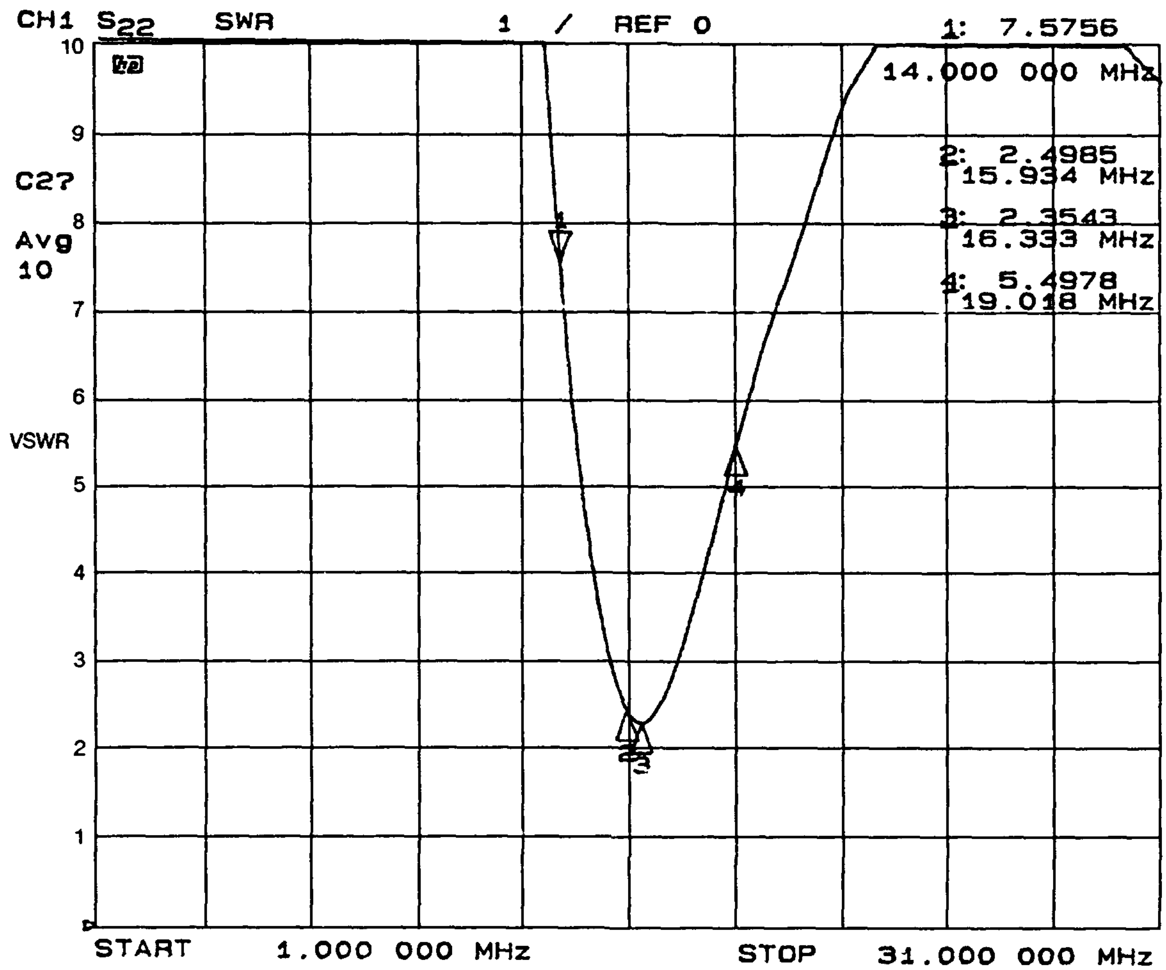


Figure A-14. VSWR (antenna of figure A-13) of water-filled, 2-inch ID antenna.

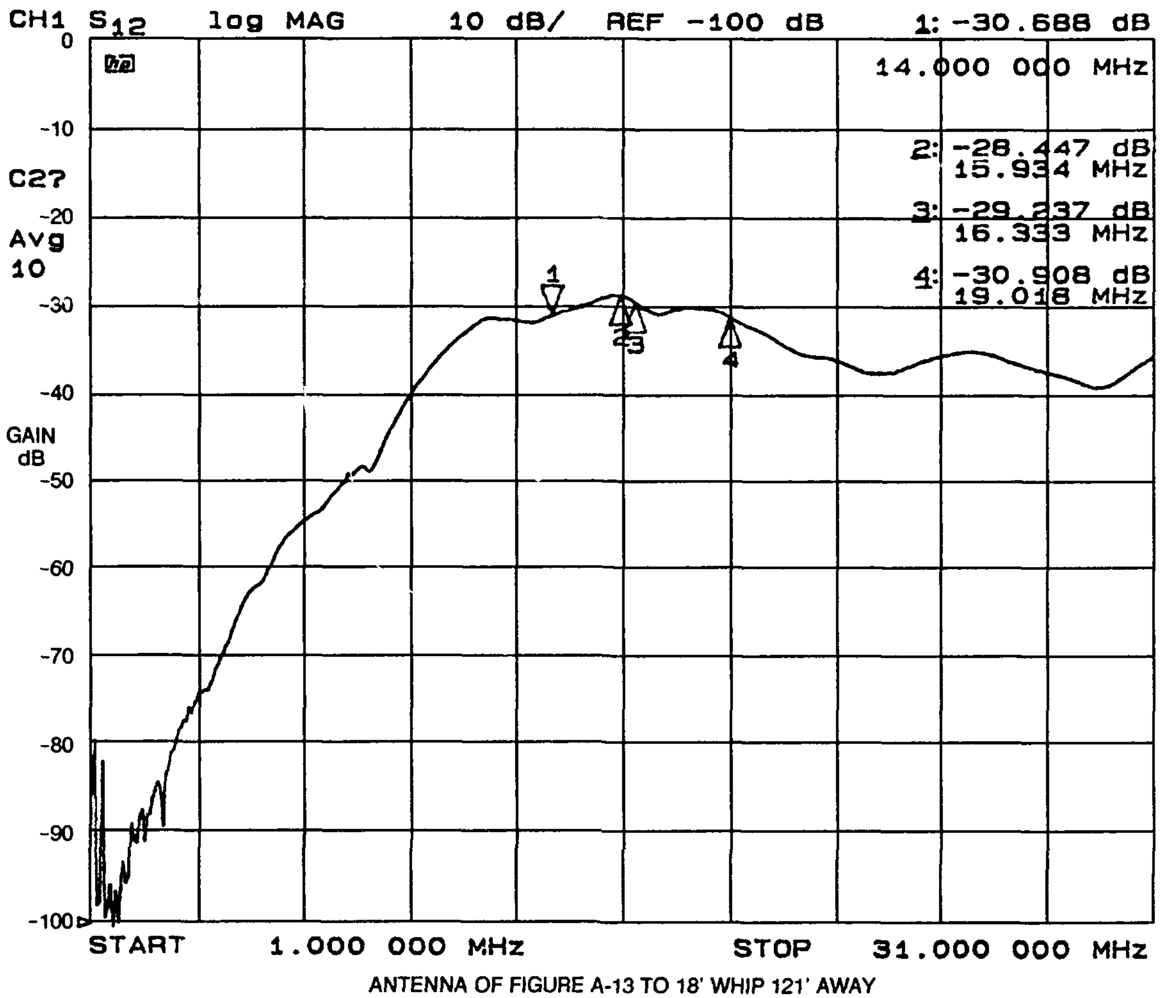


Figure A-15. Gain (antenna of figure A-13) of water-filled, 2-inch ID antenna.

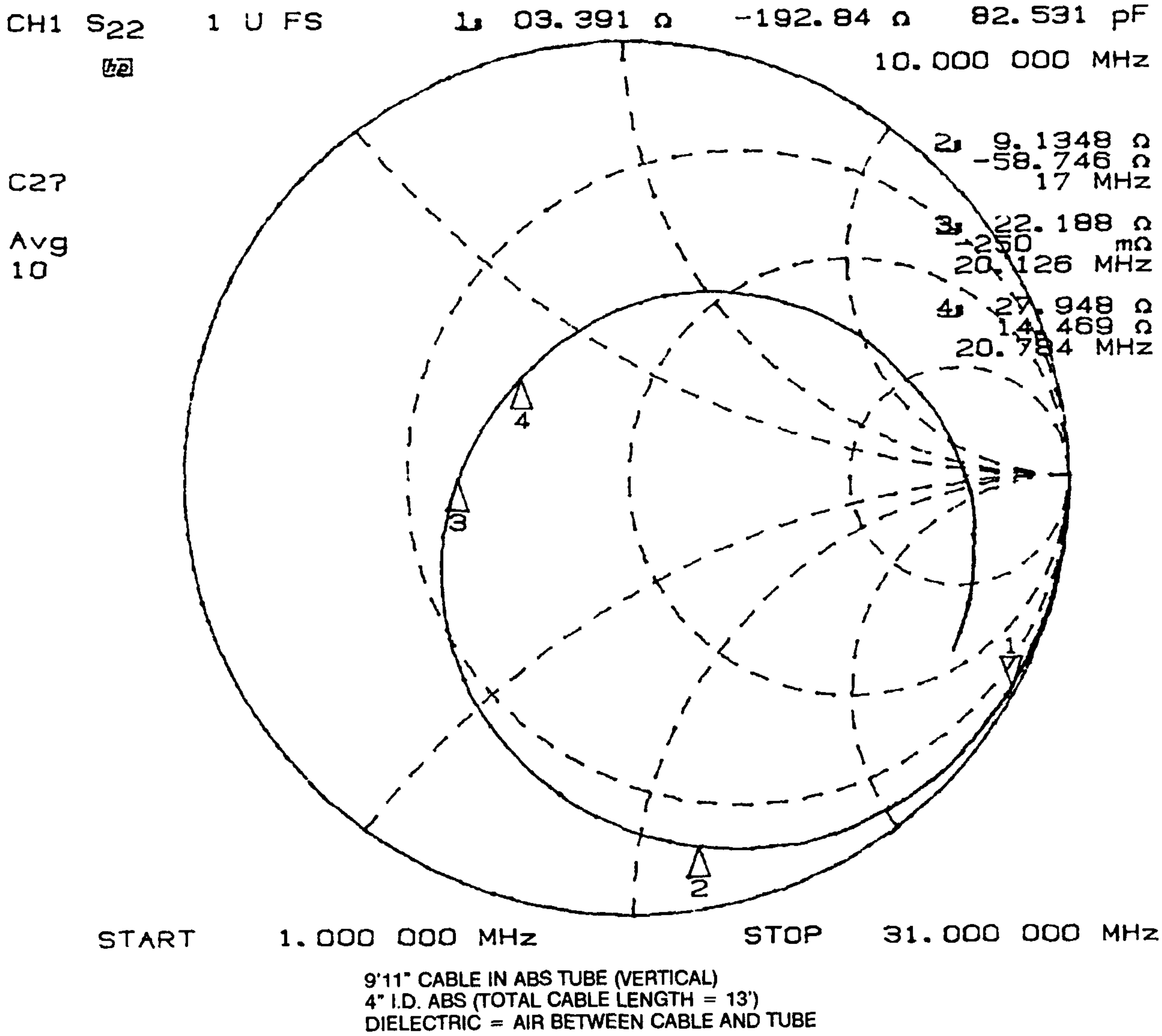


Figure A-16. Impedance of air-filled, 4-inch ID antenna.

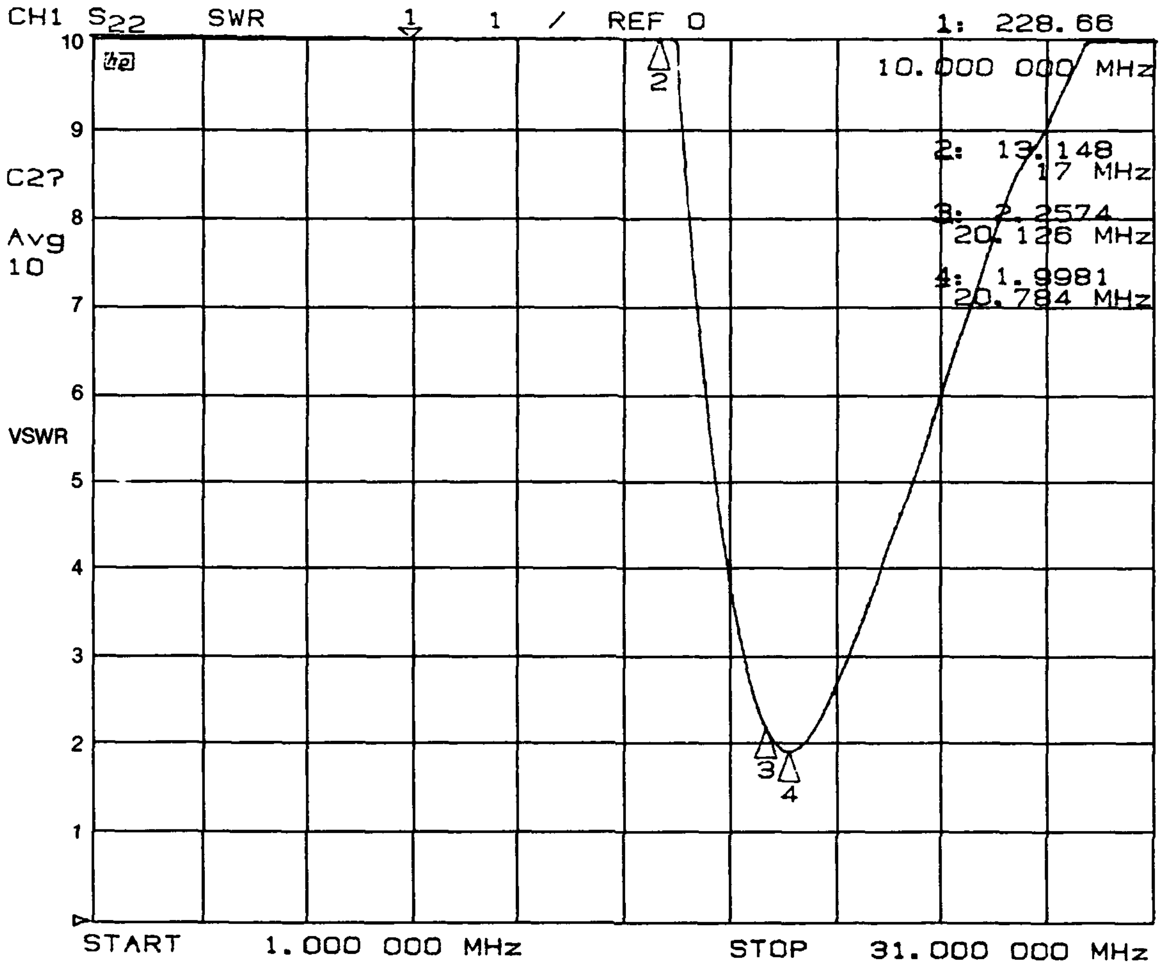
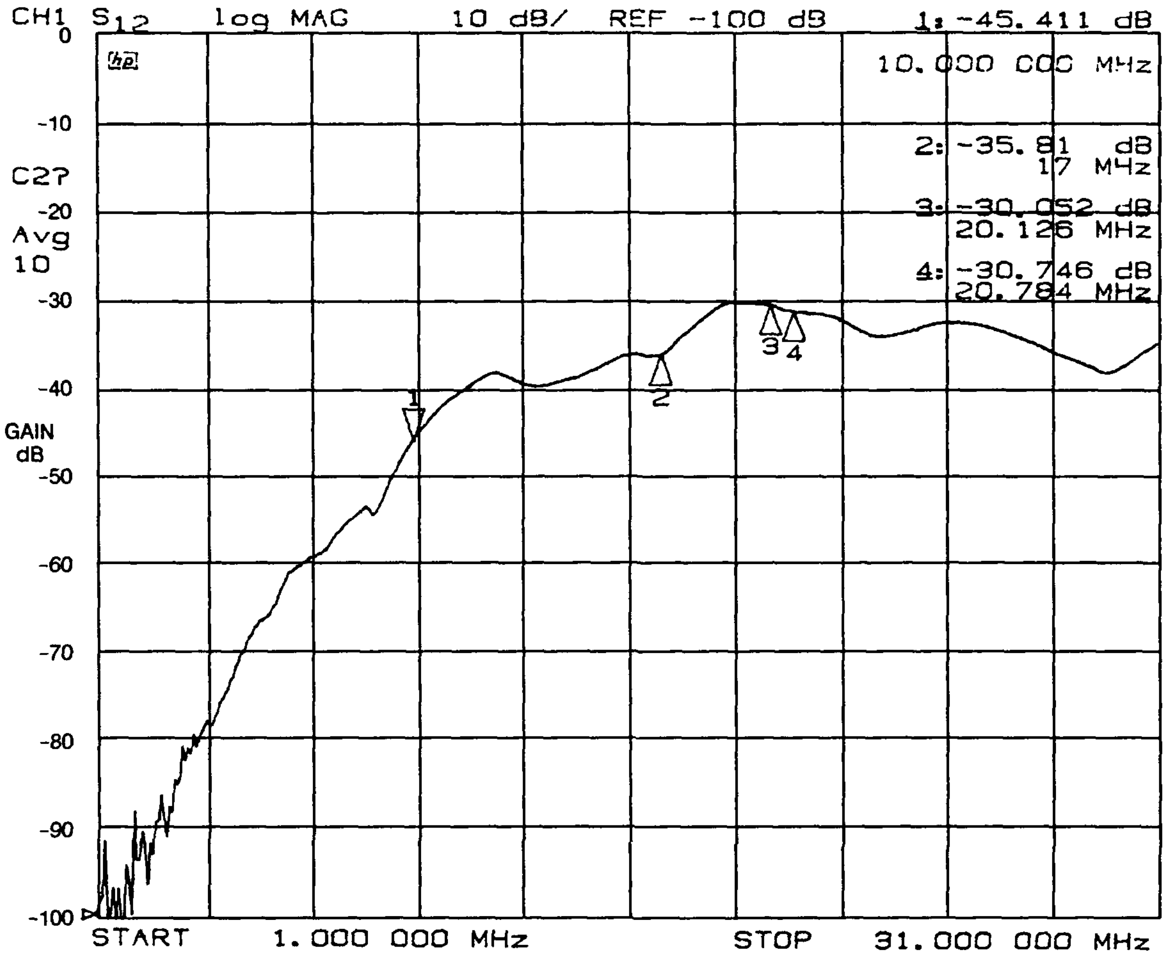


Figure A-17. VSWR (antenna of figure A-16) of air-filled, 4-inch ID antenna.



ANTENNA OF FIGURE A-16 TO 18' WHIP 121' AWAY

Figure A-18. Gain (antenna of figure A-16) of air-filled, 4-inch ID antenna.

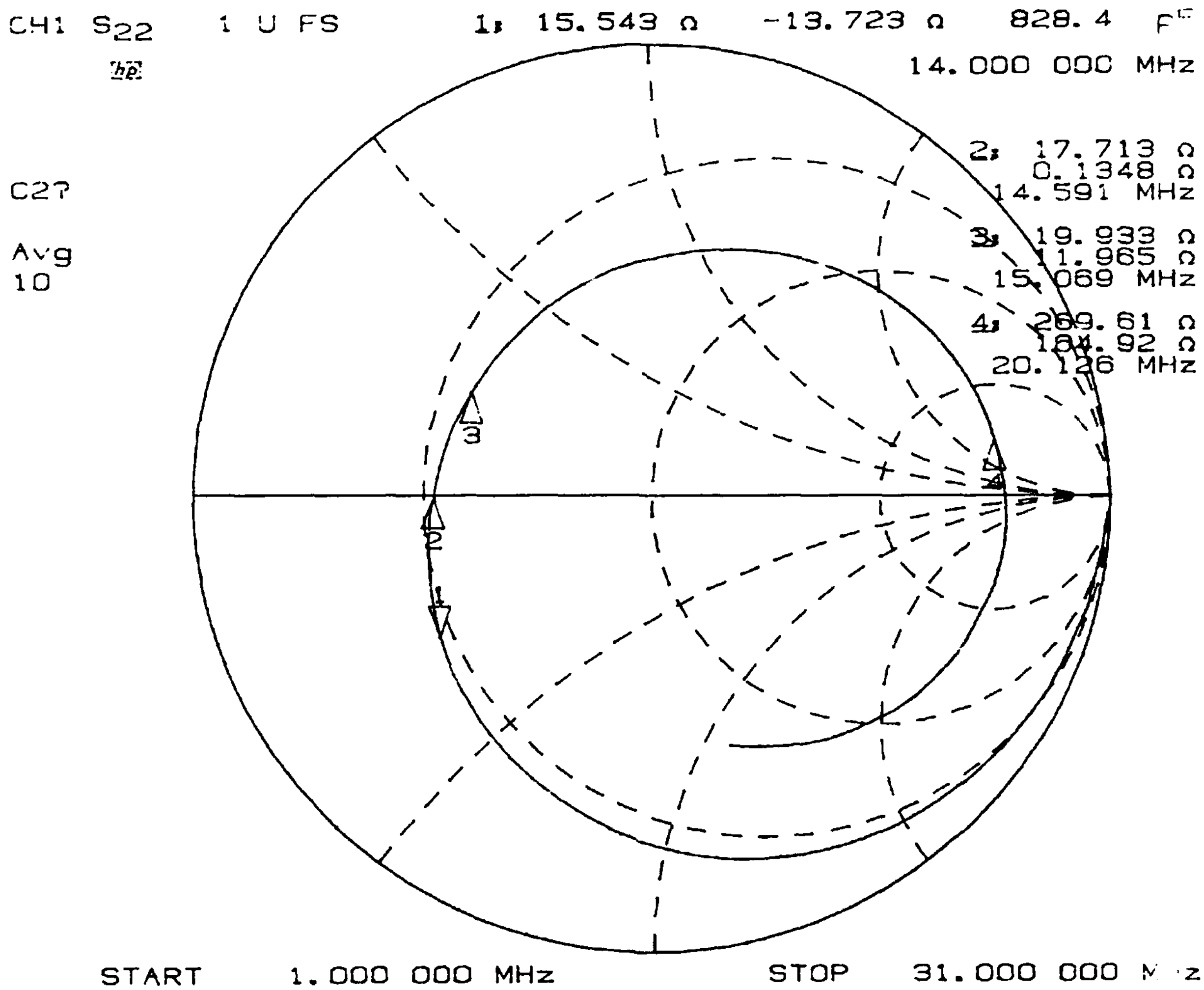


Figure A-19. Impedance of water-filled, 4-inch ID antenna.

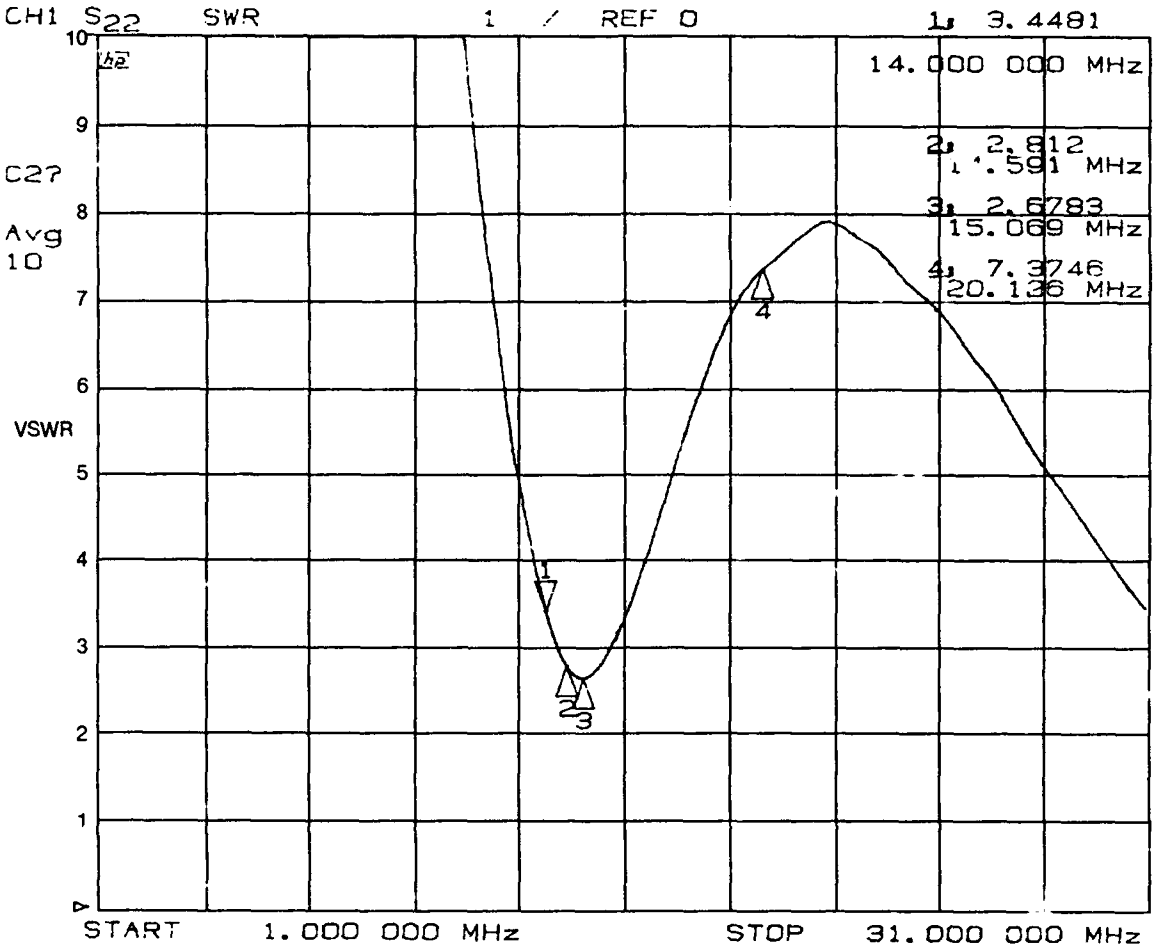
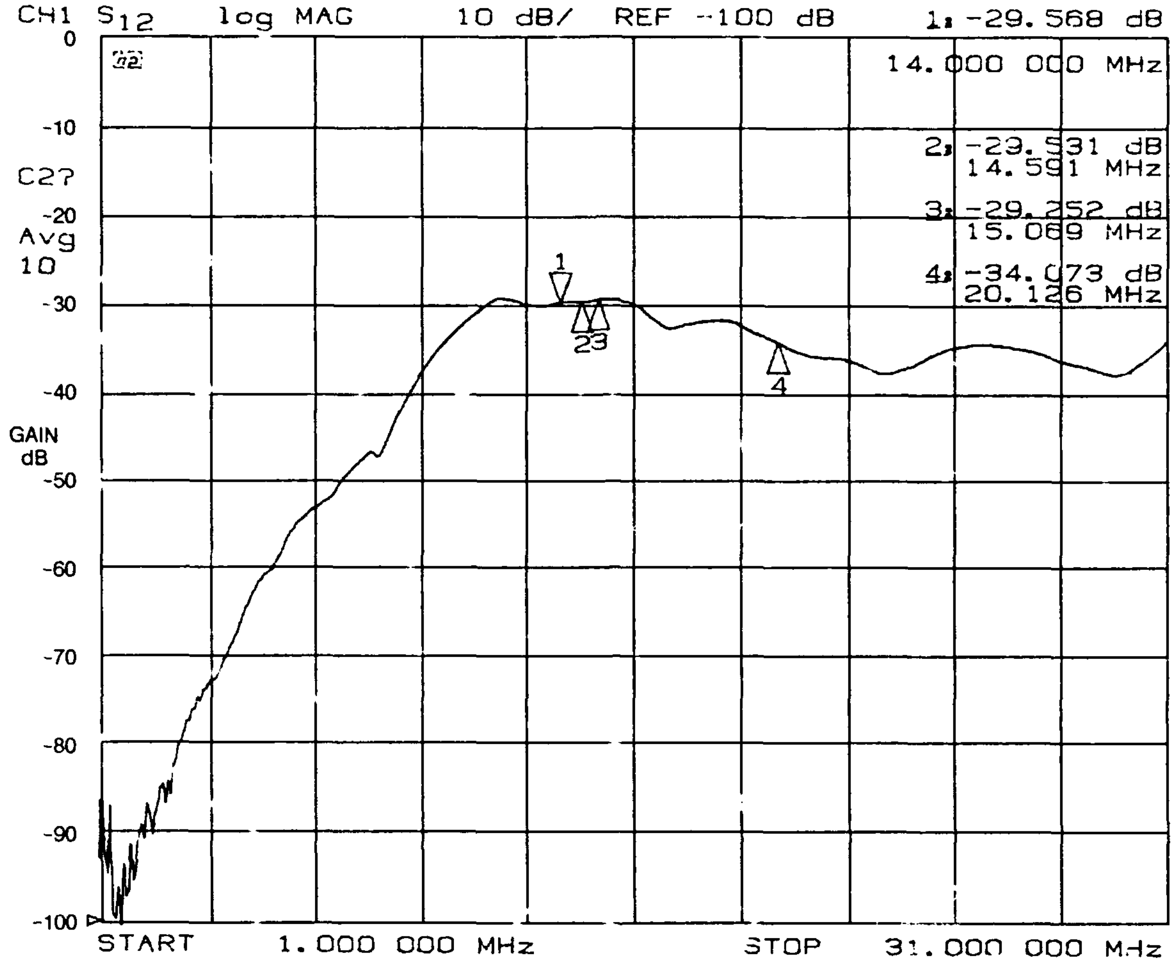


Figure A-20. VSWR (antenna of figure A-19) of water-filled, 4-inch ID antenna.



ANTENNA OF FIGURE A-19 TO 18' WHIP 121' AWAY

Figure A-21. Gain (antenna of figure A-19) of water-filled, 4-inch ID antenna.

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This report presents the results of an investigation of various techniques to design a 2- to 6-MHz transmit antenna having reduced dependence on the ship mast and superstructure. Such an antenna is needed as a replacement for the existing fan antenna for future ships constructed extensively of composite materials. Additional benefits of such an antenna are improved survivability and less obstruction of other ship systems than currently used designs

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